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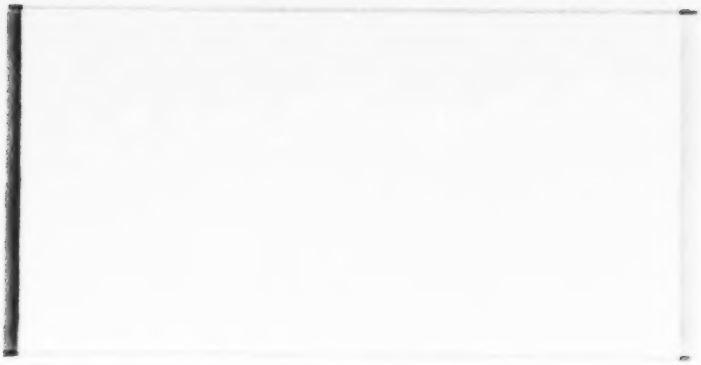

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# OPERATIONAL ENERGY PLANNING FACILITIES IN ONTARIO HYDRO

Report No 85-167-K

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## ABSTRACT

Energy Planning (EP) capabilities form an essential part of Ontario Hydro's Bulk Electricity System Tactical Operating Plan (BESTOP) facilities. The function of the EP module is to provide forecasts of the energy produced by each of the generating resources - hydraulic, fossil and nuclear - so as to satisfy the forecast load and secondary sales at minimum cost, taking into account constraints such as major transmission limits, generator loading rates and random events such as forced outages.

This project is the first phase of an investigation involving comparisons of the models with those available in the industry, and possible enhancements for use in Ontario Hydro. At this stage, it was felt that a clear rationale for the need for an integrated energy planning system should be established. This report outlines the history of energy production planning in the power industry, the need for an integrated energy planning system in Ontario Hydro, and the energy planning system that is being developed by the Resource Utilization Department.



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# EXECUTIVE SUMMARY
# OPERATIONAL ENERGY PLANNING FACILITIES IN ONTARIO HYDRO

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Economic reliable operation of Ontario Hydro's Bulk Electricity System requires comprehensive operational planning. Recently, such a plan known as the Bulk Electricity System Tactical Operating Plan (BESTOP) has been conceived by the Power Systems Operations Division. The primary goal of BESTOP is to establish a minimum-cost, security-constrained BES deployment plan. Energy Planning (EP) facilities form an essential part of the BESTOP process. The function of the EP module is to provide forecasts of the energy produced by each of the generating resources - hydraulic, fossil and nuclear - so as to satisfy the forecast load and secondary sales, taking into account constraints such as major transmission limits, generator loading rates and random events such as forced outages.

An integrated system of EP computer models consisting of 4 major modules is currently under development by the Resources Utilization Department. The hydraulic model HYMOD, the fossil model FOMOD and the nuclear model NUMOD will simulate the operation of the three types of generating units and the interface flow model IFMOD performs preliminary checks of major transmission limits. The first stage of the development of FOMOD has been completed. FOMOD I performs a Monte-Carlo simulation of the operating cycles of the fossil generating units and provides forecasts of the expected hourly energy production for each unit. The development of the other modules is expected to begin shortly.

This project is the first phase of an investigation involving comparisons of the models with those available in the industry, and possible enhancements for use in Ontario Hydro. It is anticipated that Ontario Hydro's final product will be of interest to other utilities as well. At this stage, it was felt that a clear rationale for the need for an integrated energy planning system should be established. This report outlines the history of energy production planning in the power industry, the need for an integrated energy planning system in Ontario Hydro, and the energy planning system that is being developed by the Resource Utilization Department.



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To Mr. A.J. Harris
Manager - Resource Utilization
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# OPERATIONAL ENERGY PLANNING FACILITIES IN ONTARIO HYDRO

## 1. INTRODUCTION

The operation of Ontario Hydro's Bulk Electricity System at minimum cost with an adequate level of reliability requires comprehensive operational planning. The Energy Planning (EP) facilities form an integral part of such a planning process. The primary function of the EP facilities is to simulate the operation of the in-service generating resources in order to provide realistic energy production forecasts within the operational planning horizon.

Up to the 1950's, Ontario Hydro's generating resources were primarily hydraulic. In the 1960's the increase in fossil-fired units with varying constraints and operating costs, forced the emergence of comprehensive production planning models which would integrate the resource types in order to minimize the overall cost. Since the 1970's, with the introduction of nuclear units, production cost optimization has become an even more complex problem, leading to the current process which involves considerable planning and computational efforts.

At the request of the Power Systems Operations Division, and as an integral part of the EP development, this document summarizes Ontario Hydro's operational planning process, describes the role of the EP facilities, and outlines the conceptual design of an integrated Energy Planning System.

## 2. HISTORICAL DEVELOPMENT OF ENERGY PLANNING

### 2.1 Past Approaches

In the power industry, earlier (pre-1960) approaches to the energy forecasting problem were based on deterministic models using the load duration curve. These models were generally referred to as production costing models and were primarily concerned with the fossil-fired system. In these models, the non-fossil (generally, hydraulic) output was assumed to be known

and the fossil load was simply the difference between the forecast load and the non-fossil output. Forced outages were incorporated by artificially derating the maximum capacities of the generating units or by increasing the durations of scheduled outages. Although it was recognized that the method was mathematically incorrect, it provided a needed first approximation to the production costing problem. Note also, that the load duration curve approach does not retain the chronology of events.

With the advent of digital computers, and with the increasing complexity of the power systems causing increasing errors in the above estimates, two new production costing methods were proposed. One was an analytical model in which the uncertainties due to load variations and the unit forced outages were represented by their respective probability distributions. The second method was a Monte Carlo simulation technique which simply simulated the performance of the system a number of times on a compressed time scale and obtained the required estimates by observing the simulated performance over the desired time horizon.

It was apparent that several approximations were needed in order to make the analytical model mathematically tractable, whereas the simulation model could be made as accurate as necessary. Nevertheless, in the power industry, the simulation approach did not gain wide acceptance, primarily because (1) it required excessive computation times, and (2) the errors associated with the approximations in the analytical model were considered to be within acceptable limits.

Since 1972, an analytical model called 'PROMOD'/1/ has been in use in Ontario Hydro. This model is based on an equivalent load concept where a generating unit is thought of as supplying its full capacity all the time, and forced outages are represented by imposing additional loads equivalent to the capacities multiplied by the forced outage rates of the generating units. A major source of inaccuracy in the model arises from the fact that, the load is modelled simply by the load duration curves for weekdays, Saturdays and Sundays and a monthly average load. That is, for a particular month, the daily load is assumed to depend only on whether it is a weekday, a Saturday or a Sunday. Note that the equivalent load duration curve still ignores the chronology of operation. The output from PROMOD is the expected monthly energy production from each of the thermal units and the associated energy costs.

Two critical parts of the PROMOD model are the unit commitment and unit dispatch modules. The unit commitment logic determines the units that would be typically scheduled to meet the load based on the average running costs of the units. The set of the

fossil units which are not specified in the input as 'must run' (because of coal contracts) is thus divided into two subsets: committed and uncommitted. The dispatch module is then used to dispatch units to meet the load as follows. All the units specified as 'must run' are first loaded. The units in the 'committed' subset are then dispatched in the order of increasing incremental costs. Finally, a second dispatch from the 'uncommitted' subset is performed, if needed.

## 2.2 The Need For a Better Approach

Ever since PROMOD was first introduced in Ontario Hydro, it has undergone several revisions and modifications to satisfy new requirements from the users. These included:

- modelling of spinning reserve requirements,
- modelling of some fuel contract restrictions,
- the addition of the West system in the modelling, taking into account the transmission limits of the ties. (In the original version, the West system was modelled deterministically).

PROMOD has also been reviewed periodically for potential sources of error, as the operating conditions became increasingly complex. In one such study/2/, the following shortcomings of the model were identified.

- Only the fossil system is being modelled probabilistically. Variations in hydraulic generation, secondary sales, secondary purchases, etc are modelled deterministically. Clearly, ignoring the uncertainties will lead to erroneous results, particularly in the mid- and long-term forecasts.
- The chronology of operation of the generating units is ignored in the model. In Ontario Hydro, there has recently been an increase in the need for forecasts on a chronological basis. Examples include the cost/benefit analysis of nuclear maneuvering (operating at less than full power) at times of excess base load capacity, the emergence of time of use rates as well as a request from the Comptroller's Division for hourly system incremental costs. In fact, the request could be satisfied only by the development of a new program.
- Daily load variations are neglected. In the PROMOD approach, the monthly load is represented by 3 basic load distributions - weekdays, Saturday and Sunday - and the forecasts are on a monthly basis.

- The transmission system is modelled on a very limited basis, resulting in discrepancies in security constrained regions of the BES, ie, regions where a transmission line outage can result in the system operating close to transmission line limits (eg Middleport).

- Several operating constraints such as cycling and two-shifting operations, start-up times, etc, are being ignored.

- The unit loading order is assumed to be constant over an entire month which may not be true in practice.

- Durations of planned outages are assumed to be whole number of months. For example, a six week planned outage and a three week planned outage are both treated as one month outages.

It was doubtful that further modifications to PROMOD could completely remove these shortcomings and a fresh start using a different approach was considered to be a more appropriate course of action.

## 2.3 Move Toward a Simulation Approach

It was becoming increasingly obvious that more and more of Ontario Hydro's needs, such as estimating excess generation, system incremental costs, etc could be fulfilled only by a model which represented the operation of the generating units on a chronological basis. A move toward a Monte Carlo simulation was felt to be the only feasible alternative. In fact, in the power industry, there has been a renewed interest in the Monte-Carlo approach/3/.

Two other factors make the choice particularly attractive. Firstly, the availability of faster computers and the recent development of a very efficient scheduling algorithm by PSOD removed most of the original objection concerning excessive CPU time. Secondly, tests showed that although the simulation program was costlier to run than the Ontario Hydro's version of PROMOD, the costs were comparable to those of an enhanced version of PROMOD being marketed in the U.S.

A system of computer models comprising Ontario Hydro's Energy Planning facilities based on the Monte Carlo approach is currently being developed. The role of the EP facilities in Ontario Hydro's operational planning process and a plan for the development of the EP modules are outlined in the next two sections.

## 3. THE OPERATIONAL PLANNING PROCESS

### 3.1 The BESTOP Concept

The Bulk Electricity System (BES) of Ontario Hydro consists of a large number of hydraulic, fossil-fired, and nuclear generating stations, and an extensive transmission network with interconnections to neighbouring facilities. The operation of the BES at minimum cost with an acceptable level of supply reliability requires comprehensive planning. In order to achieve the goal of optimum operation, an operational planning process known as the Bulk Electricity System Tactical Operating Plan (BESTOP) has been conceived. References 4 and 5 describe the overall concept of BESTOP.

The goals of BESTOP are to establish an economic, security constrained, BES deployment plan for the short- and mid-term operating horizons, and estimate the corresponding costs. The primary output of the BESTOP process are a BES deployment plan and the measurement of the Bulk Electricity System basic energy cost (BES:BEC). This measurement is derived from BESTOP in the form of a series of security constrained 'snapshots' of the BES deployment which minimizes BES:BEC. The creation of these snapshots requires considerable computation efforts, and the computational modules as described in Reference 4 are shown in Figure 1.

### 3.2 The Role of Energy Planning in BESTOP

The Energy Planning (EP) facilities form an essential link in the computational aspect of the BESTOP process. As shown in Figure 1, the EP module will use the optimized generation and transmission outage schedule from the Transmission Generation Outage Optimizer (TGOO) module, and data from the BESTOP primary data base to determine the forecast of energy production from each of the generating resources - hydraulic, fossil and nuclear, as well as purchases from other utilities, which would satisfy the forecast load and secondary sales. Specifically, the EP module will provide forecasts of

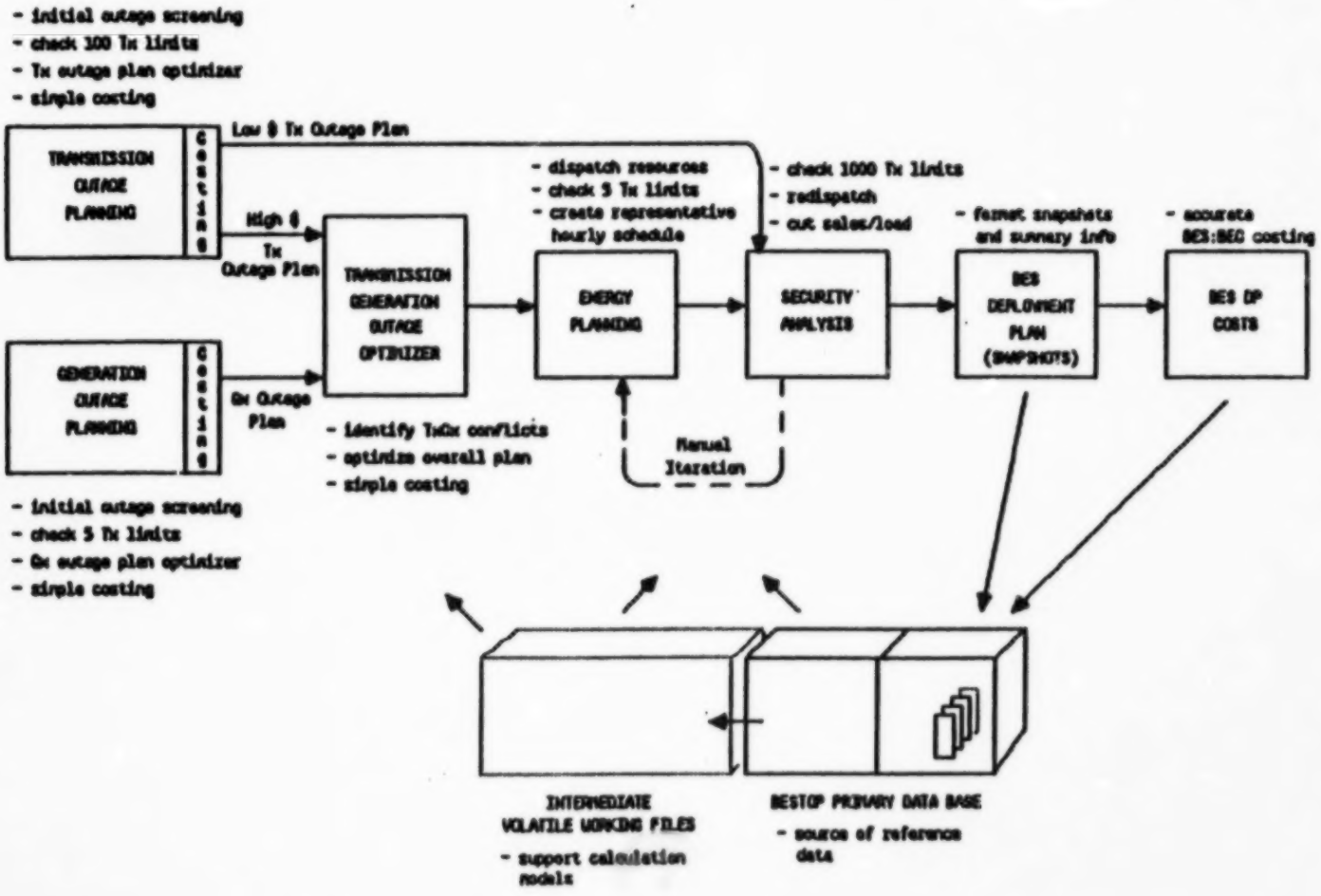
- resource requirements for the various plants over the operating time horizon,
- costs of production,
- energy output of each plant/unit.

It will also

- identify potential problem areas such as excess baseload generating capacity,

FIGURE 1

# COMPUTATIONAL ASPECTS OF BESTOP PRIMARY CAPABILITIES




Source: Reference 4

- assess impact of different operating strategies on production cost.

Many constraints on the generating unit operations, such as loading rates, emission restrictions and transmission constraints, and random events such as forced outages will be taken into account. Weekly or monthly average hydraulic energy forecast will be provided to the EP module by river regulation models. EP will have the capability to produce representative hourly generation dispatches over the entire time horizon. The generation will be economically dispatched and partially security constrained for the few (about 5) most important security limits on the BES. These representative dispatches will be passed on to the Security Analysis (SA) module, which will check the dispatch against a detailed set of security limits. If SA is unable to redispatch the generation within the given limits in SA to eliminate the violations, a manual iteration back to the EP module will be necessary.

EP will also calculate what the dispatch would have been if the security limits did not exist. This dispatch is required in order to assess the total cost impact of all security limitations.

## 4. AN INTEGRATED ENERGY PLANNING SYSTEM

### 4.1 Functional Requirements

Ontario Hydro's generating system consists of a combination of hydraulic, fossil-fired and nuclear units. The various generating units are subjected to different operating constraints and have different operating costs. For example, the hydraulic units have the lowest operating costs but are constrained by the availability of water and river control regulations. The fossil-fired units have the highest operating costs and are often operated in a cycling mode. They are constrained by such factors as loading and unloading rates, emission restrictions and minimum running times. The nuclear units are used for base-load operation, but the outputs from the Bruce stations are subjected to possible transmission capacity limitations.

In order to achieve operating economy and other required functions in BESTOP, a detailed set of functional requirements for the EP facilities, taking into account the various operating conditions and constraints listed above, have been formulated and are described in Reference 4. The requirements include

- the capability to forecast the energy production from the various resources with an hourly resolution;

- the capability to incorporate operating constraints and inflexibilities such as
  - loading and unloading rates,
  - start-up restrictions,
  - fuel contracts,
  - cycling and two shifting operations,
  - emission restrictions;
- the capability to model probabilistically the uncertainties associated with
  - generator forced outages,
  - hydraulic energy availability,
  - weather effects on transmission limitations,
  - fuel supply interruptions.

An integrated EP system which can satisfy these requirements is described below.

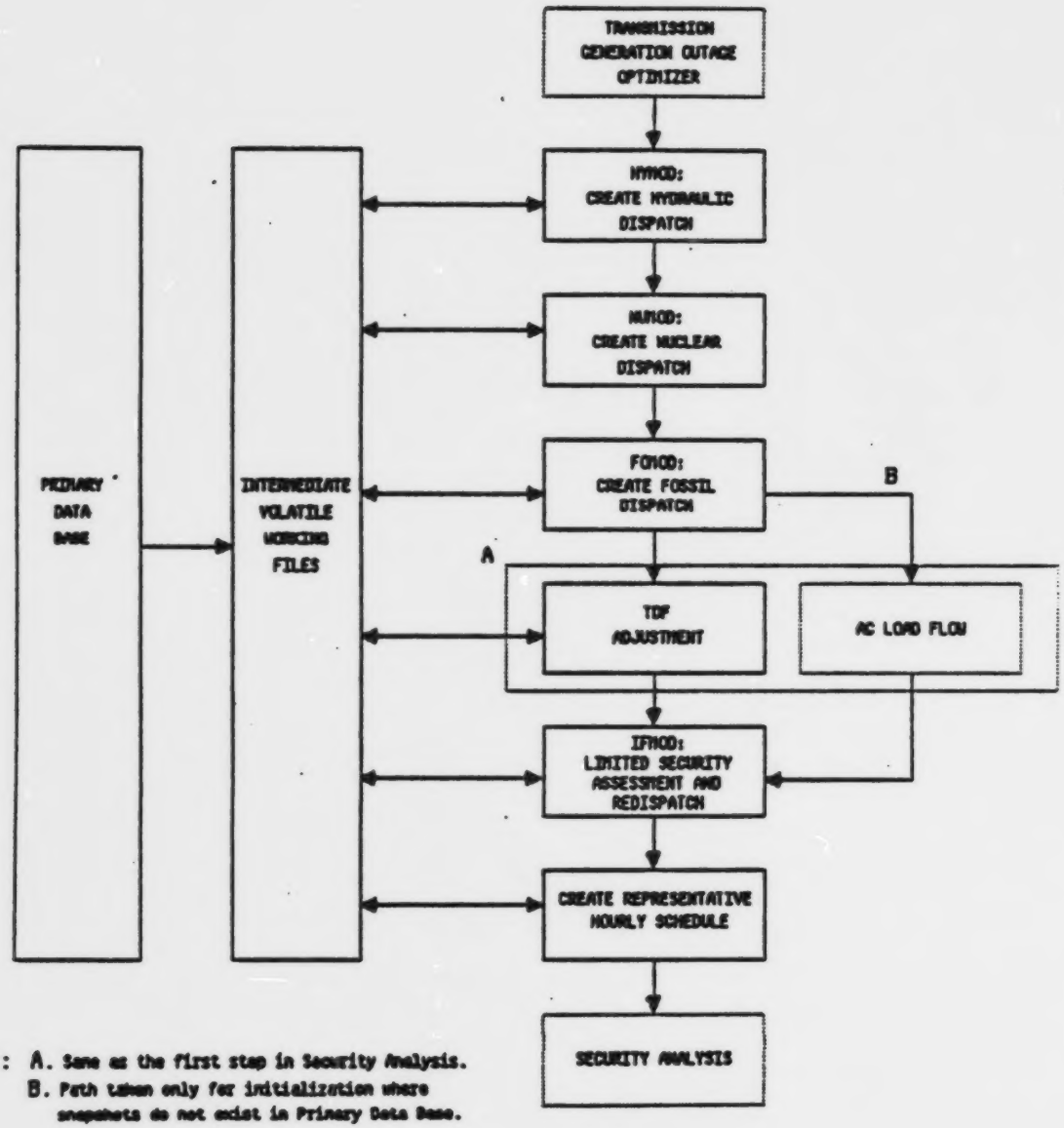
## 4.2 Description of the Overall Plan

An integrated system of computer models for energy planning to the operating horizon is currently under development. The overall concept of the system is shown in Figure 2. Although, ideally, one would prefer to have a single module representing the entire generating system, here it has been divided into three separate modules, one for each type of resource, because of the following reasons. Firstly, this approach will help reduce the dimensionality of the problem to a manageable size. Secondly, the operating constraints, uncertainties and the basic production processes, and therefore the simulation technique, are in general, different for different types of generating resources. Finally, the use of separate modules will allow early introduction of each module into the production process and will minimize disruptions during subsequent modifications and enhancements.

The EP facilities in fact consist of four major modules: the hydraulic module HYMOD, the fossil module FOMOD, and the nuclear module NUMOD and in addition, an interface module IFMOD. The general functional flow is as follows. HYMOD is first used to provide a basic hydraulic schedule. NUMOD then forecasts the

FIGURE 2

# ENERGY PLANNING MODULE




NOTE: A. Same as the first step in Security Analysis.
B. Path taken only for initialization where snapshots do not exist in Primary Data Base.

Source: Reference 4

energy output from the nuclear sources. NUMOD and HYMOD act together to minimize the production requirement on fossil generation. If excess generation exists, adjustments to the hydraulic generation may be necessary to reduce the amount of the excess. In this case, the two modules act together to maximize the use of the hydraulic resource taking into account the operating flexibility of the hydraulic resources (hydraulic transfer, tactical spill, etc) and the relative inflexibility of the nuclear resources (nuclear maneuvering, minimum generation, etc). FOMOD then simulates the operation of the fossil-fired units to satisfy the remaining load. Finally, the interface flow module IFMOD checks the power flows at major interfaces for security violations and redispatches the generation whenever necessary. Although the four modules are described as separate entities, they are integrated into one system for energy planning and there is considerable amount of interaction between the modules.

The design of the individual modules is currently under way. The design philosophy emphasizes consistency of methodology between the various modules. It will also ensure that the current production capability is maintained throughout the development stages.

### 4.3 Model by Model Summary

As mentioned earlier, EP consists of four major models: HYMOD, FOMOD and NUMOD simulate the operation of the hydraulic, fossil and nuclear generating units respectively, and IFMOD performs preliminary security checks. The functions of these models are outlined below.

The Hydraulic Model (HYMOD): It performs week-to-week and month-to-month hydraulic storage management for operational purposes using the results obtained from the river regulation models. These complex models optimize the operation of the river basins in detail, taking into account complexities such as the geographic characteristics of the individual generating plants and the effect of runoff forecasting uncertainty. Based on the longer term operational plans provided by the river regulation models, the HYMOD makes projections of the hour-to-hour allocation of hydraulic resources.

The Nuclear Model (NUMOD): This model simulates the hour-to-hour operation of the nuclear generating units in order to produce a realistic forecast of nuclear resource utilization. The model takes into account such factors as random failures (forced outages), the capability of maneuvering or shutting down selected units during periods of excess baseload generating capacity, and locked-in energy due to major transmission limitations.

The Fossil Model (FOMOD): This model simulates the hour-to-hour operation of the fossil generating units to satisfy a given fossil demand. It provides a short-and mid-term forecast of expected generation from the fossil units as well as a system incremental cost profile.

The Interface Flow Model (IFMOD): The energy plans produced by the models for the generating resources will be assessed in detail for network security by separate security analysis facilities in the BESTOP process. In order to minimize computations in the planning process, IFMOD is used to check major interface flow limits for security violations and to provide an opportunity for constraining generation output to observe these limits.

## 5. CURRENT SYSTEM CAPABILITIES

### 5.1 Status of EP Modules

Of the four major modules which comprise the EP facilities, attention so far has been focussed primarily on the fossil model FOMOD. Development of FOMOD has been under way for some time and a production version (FOMOD-Stage I) is available. FOMOD I performs a Monte-Carlo simulation of the operating cycles of the fossil generating units and provides forecasts of the expected hourly energy production for each unit. The model incorporates various operating constraints and random events such as forced outages and repairs. The features of the present version include

- simulation of the chronology of the operation of the fossil units;
- incorporation of
  - start-up restrictions,
  - unit loading and unloading rates,
  - minimum down-times;
- recognition of forced-out, two-shifted and must-run units;
- incorporation of planned outage schedules with a daily resolution.

The design and development of FOMOD - Stage II is currently under way. The additional capabilities will include

- operating reserves,

- prespecified dispatch,

- probabilistic modelling of the West system.

The design plans for HYMOD and NUMOD have been formulated and program development is expected to begin shortly. The functions of HYMOD are currently performed by two modules, the Hydraulic Energy Production Program (HEPP) and the Resources Allocation Program (RAP). These modules produce an hourly schedule of the base and peaking hydraulic resources for a typical week each month. The functions of NUMOD are currently served by the Nuclear Capacity Program (NUCAP) which produces an hourly profile of energy production from each generating unit. These models are intended solely as first approximations and do not take into account any operating restrictions, random events or uncertainties. Work on IFMOD has not started yet.

### 5.2 The Role of EP in the Production Process of the Consistent Energy Set

The EP facilities will also be used to support corporate studies involving energy forecasts such as the production of the Consistent Energy Set (CES). CES is a forecast, made by the Production Branch, of the energy produced and received by Ontario Hydro. The forecast, normally made twice a year, covers the current year and five future years, and is a primary input to the corporate budget process.

Functionally, the role of the EP facilities in the CES production process is no different from its role in the BESTOP process. The primary function in both cases is to forecast the economic use of the various generating resources for energy production. In the current CES production process, the forecasts of the primary demand, sales, purchases and hydraulic and nuclear generation are used to derive a demand on the fossil system. A detailed simulation of the fossil units is then performed to forecast the fossil generation. FOMOD has been a part of the CES process for the past three years. The other modules comprising the EP facilities (HYMOD, NUMOD and IFMOD) will be phased into the process as they are developed.

## 6. OUTLOOK

This document is the outcome of the first phase of an investigation into the potential marketing of EP facilities. The second

phase is expected to begin shortly and will include studies of how the EP program capabilities can be further enhanced, and comparisons with other energy planning programs.

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REFERENCES


1. "PROMOD VER 80.1 User's Manual", S. Leung and C.G. Garcia, Power System Operation Division, September 1980.

2. "New Production Costing Model", L.M. Szeto, PSOD DWP-RU-32 Phase I Closure Report, April 1982.

3. "BENCHMARK - A Computer Program for Simulation of Hourly Generation", EPRI Draft Report 1808-4, September 1984.

4. "BESTOP Functional Specifications for Primary Capabilities Study". D-1 Closure Report for DWP-IC-135, PSOD Report No 400.0023, June 1984.

5. "BESTOP - An Operational Planning Process", W.H. Winter, CIGRE Session 30, Group 37, Paris, September 1984.